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**Yoneda et al.**

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(54) **METHOD FOR ESTIMATING THERMAL SENSATION, THERMAL SENSATION ESTIMATION APPARATUS, AIR CONDITIONER, AND RECORDING MEDIUM**

(71) Applicant: **Panasonic Corporation**, Osaka (JP)

(72) Inventors: **Aki Yoneda**, Hyogo (JP); **Koichi Kusukame**, Nara (JP); **Hiroko Kubo**, Nara (JP)

(73) Assignee: **PANASONIC CORPORATION**, Osaka (JP)

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Dec. 15, 2016 (JP) ................................ 2016-243585

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***A61B 5/01*** (2006.01)
***A61B 5/00*** (2006.01)
*F24F 120/10* (2018.01)

(52) **U.S. Cl.**

CPC ....... ***B60H 1/00742*** (2013.01); ***A61B 5/0075*** (2013.01); ***A61B 5/0077*** (2013.01); ***A61B 5/015*** (2013.01); ***A61B 5/6893*** (2013.01); ***B60H 1/00792*** (2013.01); *A61B 2576/00* (2013.01); *F24F 2120/10* (2018.01)

(58) **Field of Classification Search**

CPC ............ B60H 1/00742; B60H 1/00792; B60H 1/00285; B60H 1/00292; F24F 2120/10; F24F 2120/12; F24F 2120/14
See application file for complete search history.

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*Primary Examiner* — Edward F Landrum
*Assistant Examiner* — Daniel C Comings
(74) *Attorney, Agent, or Firm* — Greenblum & Bernstein, P.L.C.

(57) **ABSTRACT**

A method for estimating thermal sensation calculates, on the basis of a thermal image, a first temperature, which is a surface temperature of a first area, and a second temperature, which is a surface temperature of a second area, calculates a first amount of heat lost on the basis of the first temperature and first information, calculating a second amount of heat lost on the basis of the second temperature and second information, obtains an area ratio of the first area to the second area, calculates a total amount of heat lost, which is an amount of heat lost from a whole body of a person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and estimates thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

**29 Claims, 7 Drawing Sheets**

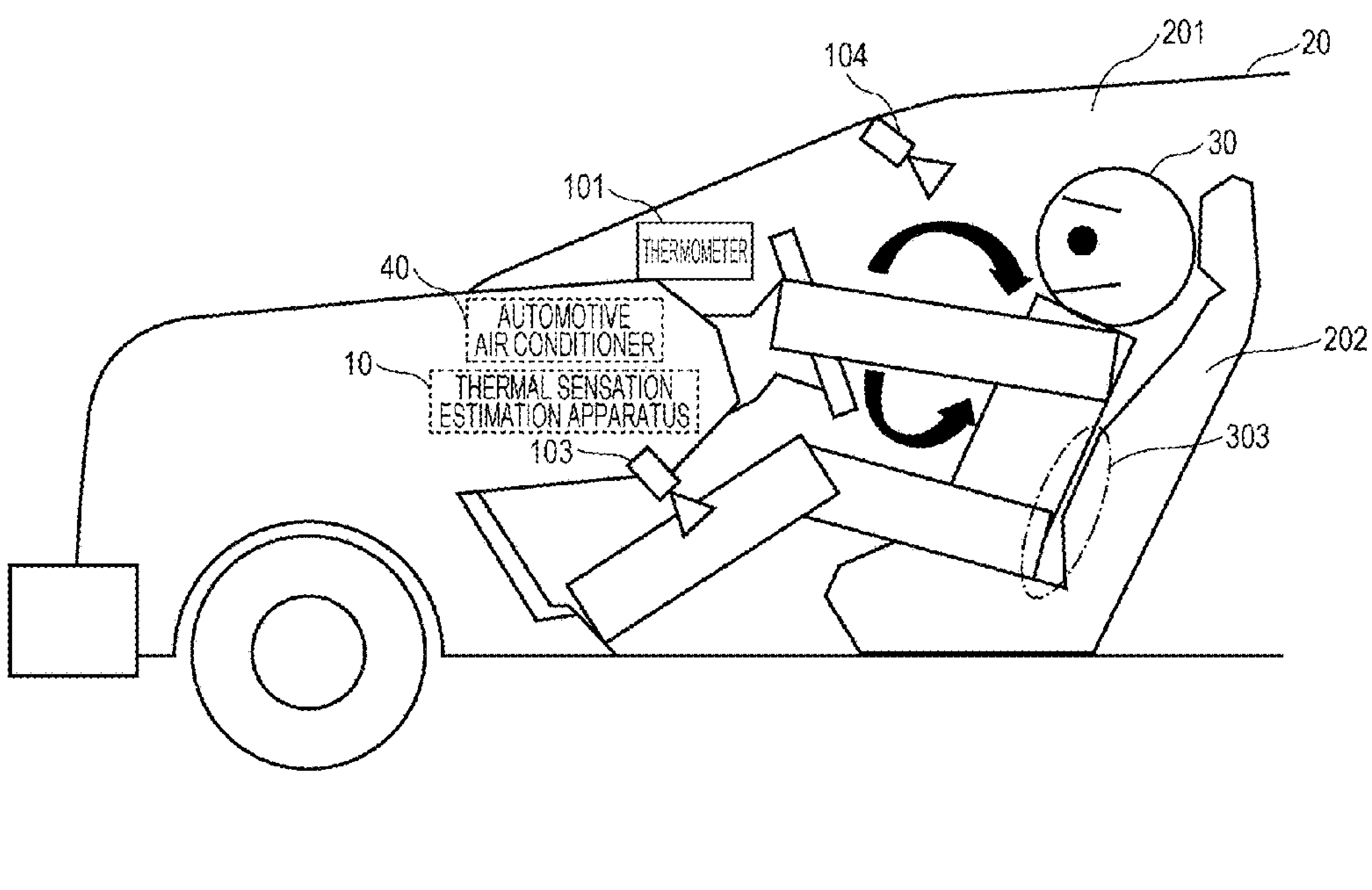


FIG. 1

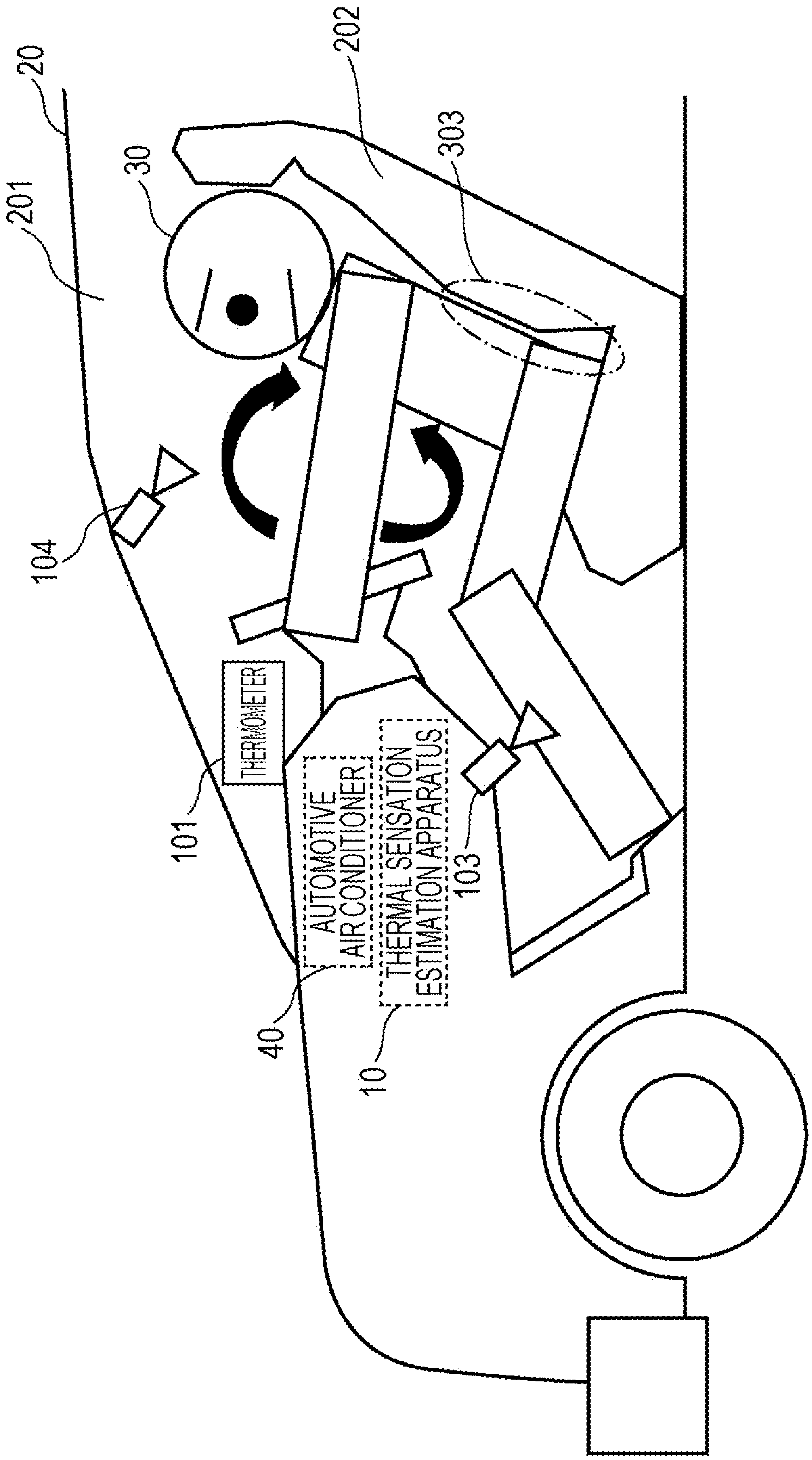

20
201
30
202
303
104
THERMOMETER
101
AUTOMOTIVE AIR CONDITIONER
40
THERMAL SENSATION ESTIMATION APPARATUS
10
103

FIG. 2

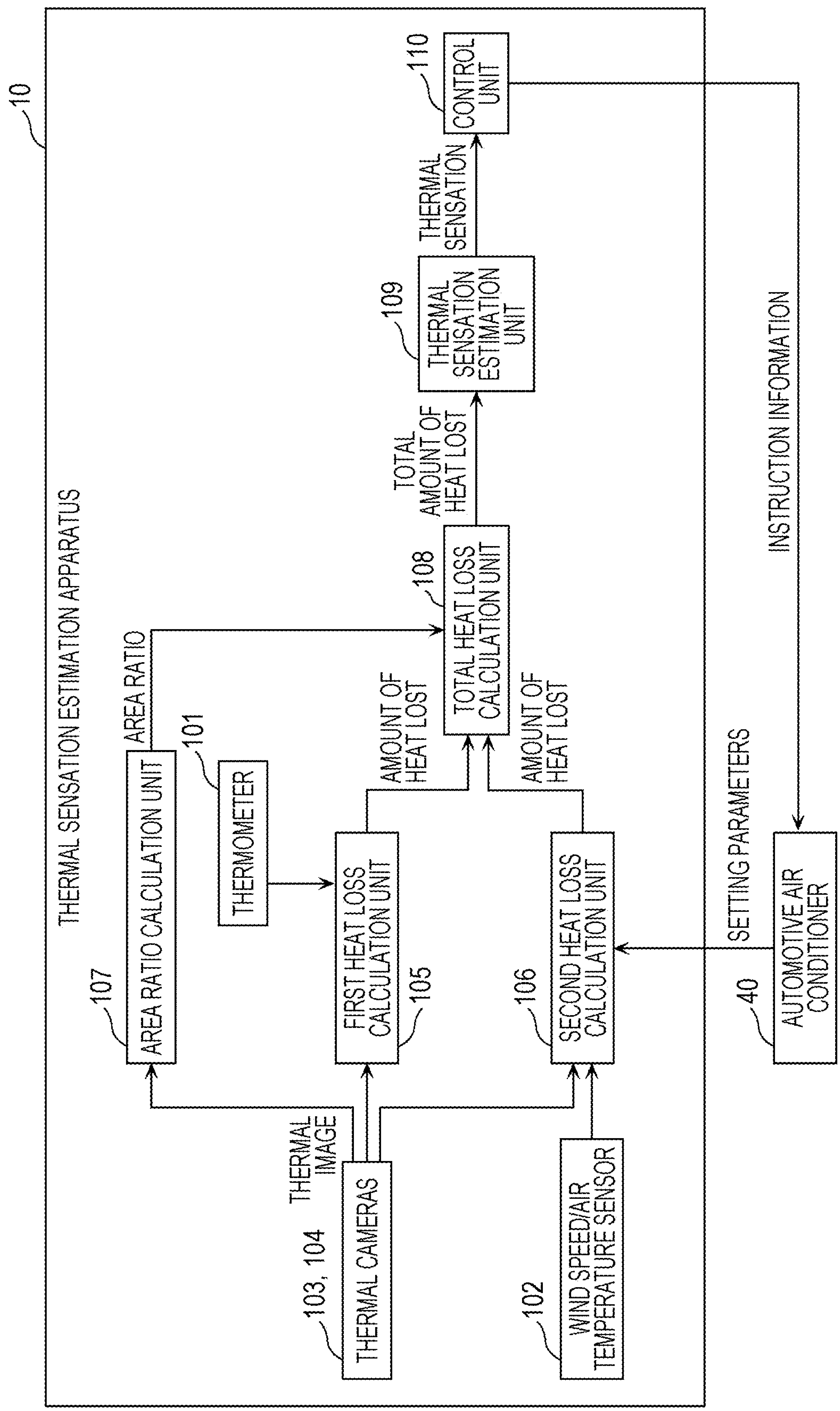

10
THERMAL SENSATION ESTIMATION APPARATUS
107
AREA RATIO CALCULATION UNIT
AREA RATIO
101
THERMOMETER
103, 104
THERMAL CAMERAS
THERMAL IMAGE
105
FIRST HEAT LOSS CALCULATION UNIT
AMOUNT OF HEAT LOST
106
SECOND HEAT LOSS CALCULATION UNIT
AMOUNT OF HEAT LOST
102
WIND SPEED/AIR TEMPERATURE SENSOR
108
TOTAL HEAT LOSS CALCULATION UNIT
TOTAL AMOUNT OF HEAT LOST
109
THERMAL SENSATION ESTIMATION UNIT
THERMAL SENSATION
110
CONTROL UNIT
INSTRUCTION INFORMATION
SETTING PARAMETERS
40
AUTOMOTIVE AIR CONDITIONER

FIG. 3

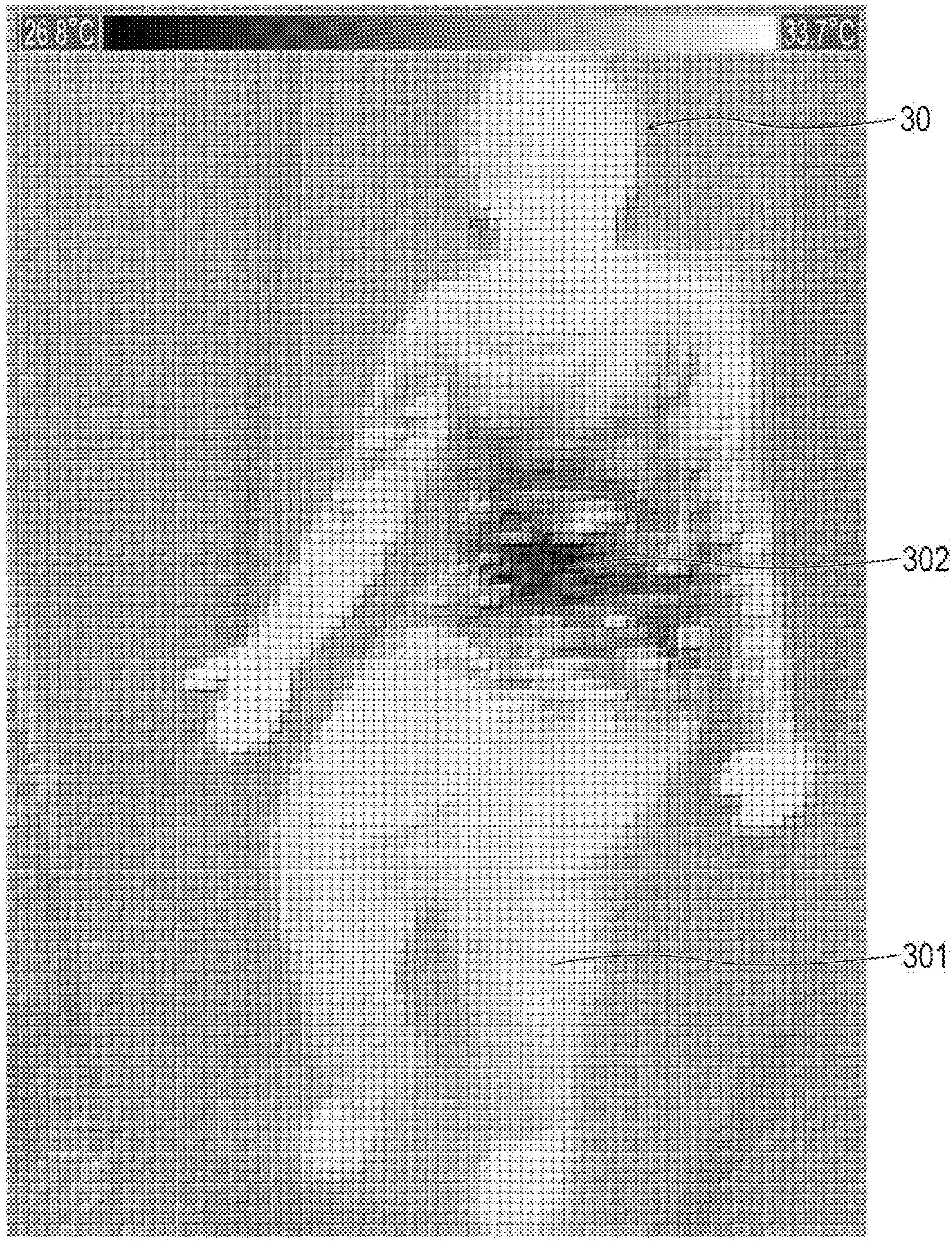


FIG. 4

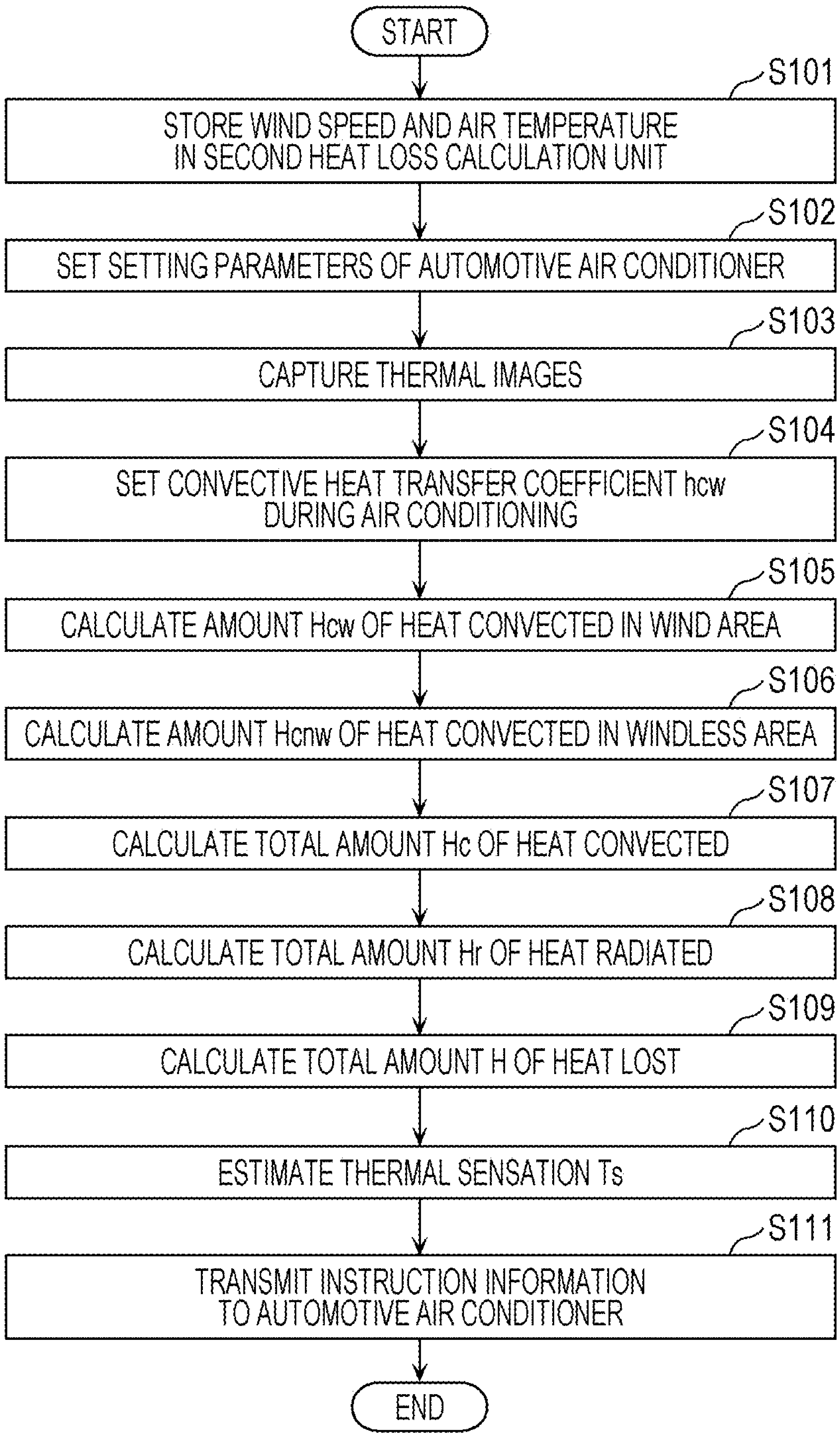
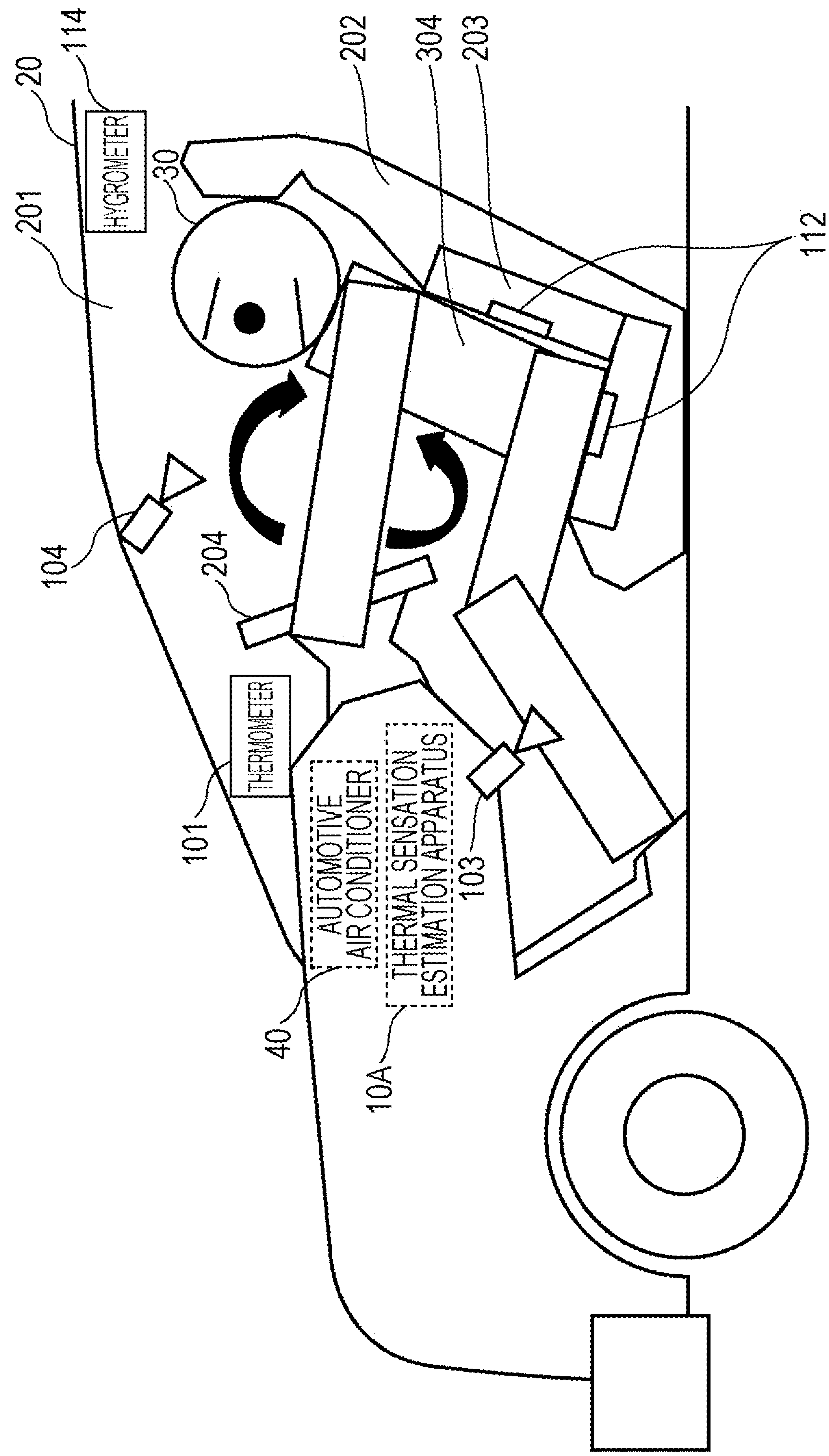

START
S101
STORE WIND SPEED AND AIR TEMPERATURE IN SECOND HEAT LOSS CALCULATION UNIT
S102
SET SETTING PARAMETERS OF AUTOMOTIVE AIR CONDITIONER
S103
CAPTURE THERMAL IMAGES
S104
SET CONVECTIVE HEAT TRANSFER COEFFICIENT hcw DURING AIR CONDITIONING
S105
CALCULATE AMOUNT Hcw OF HEAT CONVECTED IN WIND AREA
S106
CALCULATE AMOUNT Hcnw OF HEAT CONVECTED IN WINDLESS AREA
S107
CALCULATE TOTAL AMOUNT Hc OF HEAT CONVECTED
S108
CALCULATE TOTAL AMOUNT Hr OF HEAT RADIATED
S109
CALCULATE TOTAL AMOUNT H OF HEAT LOST
S110
ESTIMATE THERMAL SENSATION Ts
S111
TRANSMIT INSTRUCTION INFORMATION TO AUTOMOTIVE AIR CONDITIONER
END

FIG. 5


HYGROMETER
THERMOMETER
AUTOMOTIVE AIR CONDITIONER
THERMAL SENSATION ESTIMATION APPARATUS
20
114
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201
202
304
203
112
104
204
101
103
40
10A

FIG. 6

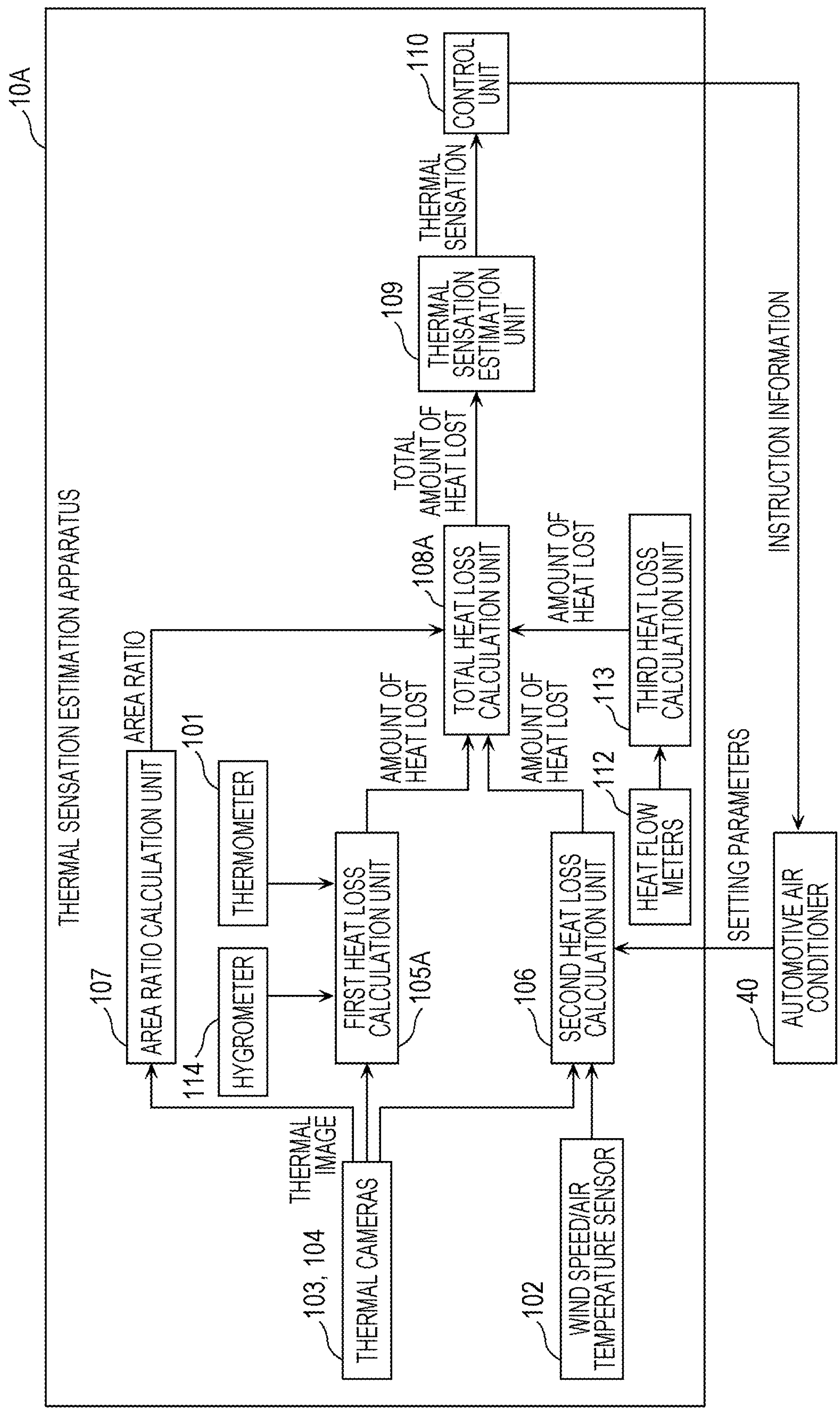
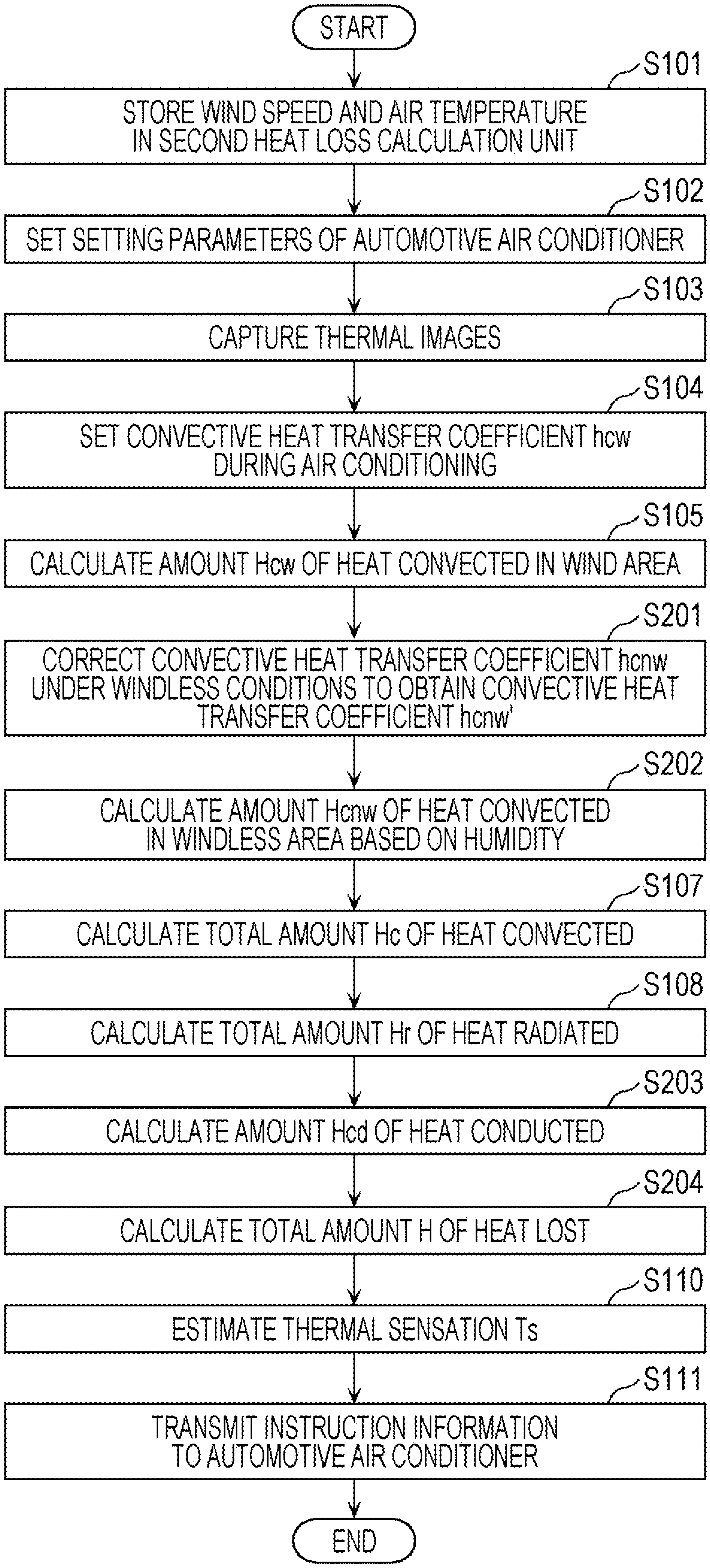

10A
THERMAL SENSATION ESTIMATION APPARATUS
103, 104
THERMAL CAMERAS
THERMAL IMAGE
102
WIND SPEED/AIR TEMPERATURE SENSOR
107
AREA RATIO CALCULATION UNIT
AREA RATIO
114
HYGROMETER
101
THERMOMETER
105A
FIRST HEAT LOSS CALCULATION UNIT
106
SECOND HEAT LOSS CALCULATION UNIT
112
HEAT FLOW METERS
113
THIRD HEAT LOSS CALCULATION UNIT
AMOUNT OF HEAT LOST
AMOUNT OF HEAT LOST
AMOUNT OF HEAT LOST
108A
TOTAL HEAT LOSS CALCULATION UNIT
TOTAL AMOUNT OF HEAT LOST
109
THERMAL SENSATION ESTIMATION UNIT
THERMAL SENSATION
110
CONTROL UNIT
INSTRUCTION INFORMATION
SETTING PARAMETERS
40
AUTOMOTIVE AIR CONDITIONER

FIG. 7


START
S101
STORE WIND SPEED AND AIR TEMPERATURE IN SECOND HEAT LOSS CALCULATION UNIT
S102
SET SETTING PARAMETERS OF AUTOMOTIVE AIR CONDITIONER
S103
CAPTURE THERMAL IMAGES
S104
SET CONVECTIVE HEAT TRANSFER COEFFICIENT hcw DURING AIR CONDITIONING
S105
CALCULATE AMOUNT Hcw OF HEAT CONVECTED IN WIND AREA
S201
CORRECT CONVECTIVE HEAT TRANSFER COEFFICIENT hcnw UNDER WINDLESS CONDITIONS TO OBTAIN CONVECTIVE HEAT TRANSFER COEFFICIENT hcnw'
S202
CALCULATE AMOUNT Hcnw OF HEAT CONVECTED IN WINDLESS AREA BASED ON HUMIDITY
S107
CALCULATE TOTAL AMOUNT Hc OF HEAT CONVECTED
S108
CALCULATE TOTAL AMOUNT Hr OF HEAT RADIATED
S203
CALCULATE AMOUNT Hcd OF HEAT CONDUCTED
S204
CALCULATE TOTAL AMOUNT H OF HEAT LOST
S110
ESTIMATE THERMAL SENSATION Ts
S111
TRANSMIT INSTRUCTION INFORMATION TO AUTOMOTIVE AIR CONDITIONER
END

# METHOD FOR ESTIMATING THERMAL SENSATION, THERMAL SENSATION ESTIMATION APPARATUS, AIR CONDITIONER, AND RECORDING MEDIUM

## BACKGROUND

### 1. Technical Field

The present disclosure relates to a method for estimating thermal sensation, a thermal sensation estimation apparatus, an air conditioner, and a recording medium.

### 2. Description of the Related Art

A thermal sensation estimation apparatus that estimates thermal sensation, which indicates a degree of warmth or coldness of a person, without a report from the person is known. When the thermal sensation estimation apparatus is installed in an automobile, for example, an automotive air conditioner can be efficiently operated by controlling air temperature of the automotive air conditioner or the like on the basis of the estimated thermal sensation.

One of thermal sensation estimation apparatuses in examples of the related art is one that estimates thermal sensation by measuring an average skin temperature of a person on the basis of a fact that the average skin temperature and the thermal sensation have a high correlation. When this kind of thermal sensation estimation apparatus is used, however, a temperature sensor needs to be directly attached to a person's skin, which is not practical.

In order to solve the above problem, a thermal sensation estimation apparatus that focuses upon the amount of heat lost to an outside from a person's skin through clothes has been proposed (e.g., refer to International Publication No. 2015/122201). The thermal sensation estimation apparatus according to International Publication No. 2015/122201 calculates the amount of heat lost from a person on the basis of a difference between a human body surface temperature measured by a thermal camera and an atmospheric temperature (air temperature) and estimates thermal sensation on the basis of the calculated amount of heat lost from the person.

## SUMMARY

In one general aspect, the techniques disclosed here feature a method for estimating thermal sensation used by a thermal sensation estimation apparatus. The method includes obtaining a thermal image of an area including a person captured by a thermal camera, calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment, calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment, calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment, obtaining an area ratio of the first area to the second area, calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

With the method for estimating thermal sensation according to the aspect of the present disclosure, thermal sensation can be accurately estimated even in a non-uniform thermal environment.

It should be noted that general or specific aspects may be implemented as a system, a method, an integrated circuit, a computer program, a computer-readable recording medium such as a compact disc read-only memory (CD-ROM), or any selective combination thereof.

Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.



## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a use case of a thermal sensation estimation apparatus according to a first embodiment;

FIG. **2** is a block diagram illustrating the configuration of the thermal sensation estimation apparatus according to the first embodiment;

FIG. **3** is an example of a thermal image obtained by the thermal sensation estimation apparatus according to the first embodiment;

FIG. **4** is a flowchart illustrating a procedure of the operation of the thermal sensation estimation apparatus according to the first embodiment;

FIG. **5** is a diagram illustrating a use case of a thermal sensation estimation apparatus according to a second embodiment;

FIG. **6** is a block diagram illustrating the configuration of the thermal sensation estimation apparatus according to the second embodiment; and

FIG. **7** is a flowchart illustrating a procedure of the operation of the thermal sensation estimation apparatus according to the second embodiment.

## DETAILED DESCRIPTION

Underlying Knowledge Forming Basis of Present Disclosure

A method for estimating thermal sensation used by a thermal sensation estimation apparatus according to International Publication No. 2015/122201 presupposes that a thermal environment (atmospheric temperature) is uniform. If a thermal environment is not uniform due to cold or warm wind from an automotive air conditioner, heat from a seat heater, or the like as in an automobile, for example, thermal sensation is not accurately estimated.

The present disclosure, therefore, provides a method for estimating thermal sensation, a thermal sensation estimation apparatus, an air conditioner, and a recording medium capable of accurately estimating thermal sensation even in a non-uniform thermal environment.

A method for estimating thermal sensation according to an aspect of the present disclosure is a method used by a thermal sensation estimation apparatus. The method includes obtaining a thermal image of an area including the person captured by a thermal camera, calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment, calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment, calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment, obtaining an area ratio of the first area to the second area, calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

According to this aspect, when the first area and the second area of a human body surface area are exposed to the first thermal environment and the second thermal environment, respectively, the first amount of heat lost and the second amount of heat lost are calculated in the first area and the second area, respectively, and the total amount of heat lost is calculated by combining the first amount of heat lost and the second amount of heat lost using an area ratio. Furthermore, thermal sensation is estimated on the basis of the total amount of heat lost calculated in this manner. That is, since the total amount of heat lost is calculated in consideration of the human body surface area exposed to a non-uniform thermal environment, thermal sensation can be accurately estimated even if a person is in a non-uniform thermal environment.

For example, the first area may include at least a part of the human body surface area not exposed to air from an air conditioner. The second area may include at least a part of the human body surface area exposed to the air from the air conditioner.

According to this aspect, thermal sensation can be accurately estimated even in a thermal environment that is non-uniform due to air from an air conditioner.

For example, the total amount of heat lost may be calculated by weight-averaging the first amount of heat lost and the second amount of heat lost using the area ratio.

According to this aspect, the total amount of heat lost can be accurately calculated by weight-averaging the first amount of heat lost and the second amount of heat lost using an area ratio.

For example, the area ratio may be calculated on the basis of an area of the first area and an area of the second area in the thermal image.

According to this aspect, an area ratio can be easily calculated on the basis of areas of the first area and the second area in a thermal image.

For example, the area ratio may be calculated on the basis of a temperature histogram of the thermal image.

According to this aspect, an area ratio can be easily calculated on the basis of a temperature histogram of a thermal image.

For example, the area ratio may be a preset value.

According to this aspect, an area ratio can be easily obtained.

For example, the thermal camera may include a first thermal camera provided at a certain position and a second thermal camera provided at a position different from that of the first thermal camera. The thermal image may include a first thermal image captured by the first thermal camera and a second thermal image captured by the second thermal camera. The first area may be identified from the first thermal image. The second area may be identified from the second thermal image.

According to this aspect, by capturing the first thermal image and the second thermal image using the first thermal camera and the second thermal camera, respectively, the first area and the second area can be easily identified even if a human body surface area is relatively large.

For example, the person may be in contact with a certain member. An amount of heat transferred between the person and the certain member in a third area, which is a part of the human body surface area in which the person is in contact with the certain member, may be calculated on the basis of an amount of heat received by or lost from the certain member. An area ratio of the first area, the second area, and the third area may be obtained. The total amount of heat lost may be calculated on the basis of the first amount of heat lost, the second amount of heat lost, the amount of heat transferred, and the area ratio.

According to this aspect, the total amount of heat lost can be accurately calculated even if a person is in contact with a certain member.

For example, the certain member may be at least either a seat of a vehicle in which the person stays or a steering wheel. The amount of heat transferred may be an amount of heat transferred on a surface of the person's body at which the person is in contact with at least either the seat or the handle.

According to this aspect, the total amount of heat lost can be accurately calculated even if a person is in contact with a seat or a steering wheel.

For example, the amount of heat transferred may be measured by a thermometer provided for at least either the seat or the steering wheel.

According to this aspect, the amount of heat transferred can be easily measured using a thermometer.

For example, the amount of heat transferred may be measured by a heat flow meter provided for at least either the seat or the steering wheel.

According to this aspect, the amount of heat transferred can be easily measured using a heat flow meter.

For example, at least either the first information or the second information may include a temperature around the person.

According to this aspect, a temperature around a person can be used as at least either the first information or the second information.

For example, at least either the first amount of heat lost or the second amount of heat lost may be calculated by a calculation method in which a difference between the first temperature or the second temperature, whichever corresponds to the amount of heat lost, and the temperature is multiplied by a certain value.

According to this aspect, at least either the first amount of heat lost or the second amount of heat lost can be easily calculated.

For example, the temperature may be calculated on the basis of a thermal image representing temperature distribution in space.

According to this aspect, a temperature can be easily calculated on the basis of a thermal image.

For example, the temperature may be measured by a thermometer provided at a certain position around the person.

According to this aspect, a temperature can be easily measured using a thermometer.

For example, at least either the first information or the second information may include radiation temperature.

According to this aspect, radiation temperature can be used as at least either the first information or the second information.

For example, the radiation temperature may be calculated on the basis of a thermal image representing temperature distribution in space.

According to this aspect, radiation temperature can be easily calculated on the basis of a thermal image.

For example, at least either the first information or the second information may include wind speed and air temperature of wind around the person.

According to this aspect, wind speed and air temperature can be used as at least either the first information or the second information.

For example, a convective heat transfer coefficient between the human body surface area and at least either the first thermal environment or the second thermal environment may be set in accordance with the wind speed. At least either the first amount of heat lost or the second amount of heat lost may be calculated on the basis of the convective heat transfer coefficient, the air temperature, and the first temperature or the second temperature, whichever corresponds to the amount of heat lost.

According to this aspect, at least either the first amount of heat lost and the second amount of heat lost can be easily calculated.

For example, at least either the first amount of heat lost or the second amount of heat lost may be calculated by a calculation method in which a difference between the first temperature or the second temperature, whichever corresponds to the amount of heat lost, and the air temperature is multiplied by the convective heat transfer coefficient.

According to this aspect, at least either the first amount of heat lost or the second amount of heat lost can be easily calculated.

For example, the wind speed and the air temperature may be wind speed and air temperature of air from an air conditioner installed in space where the person stays.

According to this aspect, wind speed and air temperature of air from an air conditioner can be used as at least either the first information or the second information.

For example, the method may further include obtaining setting parameters of the air conditioner and calculating at least either the first amount of heat lost or the second amount of heat lost using the wind speed and the air temperature set using the setting parameters.

According to this aspect, wind speed and air temperature can be easily set using setting parameters of an air conditioner.

For example, the method may further include measuring in advance the wind speed and the air temperature at each position in the space for each pattern of the setting parameters of the air conditioner, estimating the wind speed and the air temperature in the human body surface area by identifying a position of the person in the space using the setting parameters of the air conditioner and the thermal image, and calculating at least either the first amount of heat lost and the second amount of heat lost using the estimated wind speed and air temperature.

According to this aspect, wind speed and air temperature can be easily estimated using setting parameters of an air conditioner and a thermal image.

For example, the first thermal environment and the second thermal environment may include humidity around the person.

According to this aspect, thermal sensation can be accurately estimated even if the first thermal environment and the second thermal environment include humidity.

For example, the method may further include outputting, to an air conditioner, instruction information for controlling air volume, air temperature, or wind direction of the air conditioner in accordance with the estimated thermal sensation.

According to this aspect, an air conditioner can be controlled such that, for example, thermal sensation becomes close to a value at which a person does not feel cold or hot. As a result, the air conditioner does not cool or heat too much, and power is saved.

For example, the thermal image may be captured inside a vehicle body of a vehicle in which the person stays.

According to this aspect, thermal sensation can be accurately estimated even in a non-uniform thermal environment such as an inside of a vehicle body of a vehicle in which a cooling operation is being performed in summer or a heating operation is being performed in winter.

A thermal sensation estimation apparatus according to an aspect of the present disclosure is a thermal sensation estimation apparatus. The thermal sensation estimation apparatus includes a processor and a memory. The processor performs operations including obtaining a thermal image of an area including a person captured by a thermal camera, calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment, calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment, calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment, obtaining an area ratio of the first area to the second area, calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

According to this aspect, when the first area and the second area of a human body surface area are exposed to the first thermal environment and the second thermal environment, respectively, the first amount of heat lost and the second amount of heat lost are calculated in the first area and the second area, respectively, and the total amount of heat lost is calculated by combining the first amount of heat lost and the second amount of heat lost using an area ratio. Furthermore, thermal sensation is estimated on the basis of the total amount of heat lost calculated in this manner. That is, since the total amount of heat lost is calculated in consideration of the human body surface area exposed to a non-uniform thermal environment, thermal sensation can be accurately estimated even if a person is in a non-uniform thermal environment.

An air conditioner according to an aspect of the present disclosure is an air conditioner including the above thermal sensation estimation apparatus. Air volume, air temperature, or wind direction is controlled on the basis of the thermal sensation estimated by the thermal sensation estimation apparatus.

According to this aspect, an air conditioner can be controlled such that, for example, thermal sensation becomes close to a value at which a person does not feel cold or hot. As a result, the air conditioner does not cool or heat too much, and power is saved.

A program according to an aspect of the present disclosure is a non-transitory recording medium storing a program for causing a computer to function as a thermal sensation estimation apparatus. The program causes the computer to perform operations including obtaining a thermal image of an area including a person captured by a thermal camera, calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment, calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment, calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment, obtaining an area ratio of the first area to the second area, calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

According to this aspect, when the first area and the second area of a human body surface area are exposed to the first thermal environment and the second thermal environment, respectively, the first amount of heat lost and the second amount of heat lost are calculated in the first area and the second area, respectively, and the total amount of heat lost is calculated by combining the first amount of heat lost and the second amount of heat lost using an area ratio. Furthermore, thermal sensation is estimated on the basis of the total amount of heat lost calculated in this manner. That is, since the total amount of heat lost is calculated in consideration of the human body surface area exposed to a non-uniform thermal environment, thermal sensation can be accurately estimated even if a person is in a non-uniform thermal environment.

It should be noted that these general or specific aspects may be implemented as a system, a method, an integrated circuit, a computer program, a computer-readable recording medium such as a compact disc read-only memory (CD-ROM), or any selective combination thereof.

Embodiments will be specifically described hereinafter with reference to the drawings.

The following embodiments are general or specific examples. Values, shapes, materials, components, arrangement positions and connection modes of the components, steps, the order of the steps, and the like mentioned in the following embodiments are examples, and do not limit the present disclosure. Among the components described in the following embodiments, ones not described in the independent claims, which define broadest concepts, will be described as arbitrary components.

## First Embodiment

### 1-1. Configuration of Thermal Sensation Estimation Apparatus

First, the configuration of a thermal sensation estimation apparatus **10** according to a first embodiment will be described with reference to FIGS. **1** to **3**. FIG. **1** is a diagram illustrating a use case of the thermal sensation estimation apparatus **10** according to the first embodiment. FIG. **2** is a block diagram illustrating the configuration of the thermal sensation estimation apparatus **10** according to the first embodiment. FIG. **3** is an example of a thermal image obtained by the thermal sensation estimation apparatus **10** according to the first embodiment.

As illustrated in FIG. **1**, the thermal sensation estimation apparatus **10** is installed in a vehicle body **201** of an automobile **20** (an example of a vehicle). The thermal sensation estimation apparatus **10** estimates the thermal sensation of a person **30** (a driver or the like) seated in (in contact with) a seat **202** (an example of a certain member) of the automobile **20** in a non-uniform thermal environment such as an inside of the vehicle body **201** in which, for example, a cooling operation is being performed in summer (or a heating operation is being performed in winter). The non-uniform thermal environment refers to, for example, an environment in which temperature inside the vehicle body **201** has become non-uniform because of air (cold or warm air) locally blown from an automotive air conditioner **40** installed in the vehicle body **201**. As described later, the thermal sensation estimated by the thermal sensation estimation apparatus **10** is used to control any of air volume, air temperature, and wind direction of the automotive air conditioner **40**. Control units of the thermal sensation estimation apparatus **10** and the automotive air conditioner **40** may be implemented as electronic control units (ECUs) and connected to a vehicle network such as a local interconnect network (LIN) or a controller area network (CAN).

As illustrated in FIG. **1**, the automotive air conditioner **40** cools or heats air inside the vehicle body **201** of the automobile **20**. The automotive air conditioner **40** blows cold air to an upper half of a body of the person **30** in a cooling operation and blows warm air to the upper half of the body and feet of the person **30** in a heating operation. In the present embodiment, a case will be described in which the automotive air conditioner **40** performs a cooling operation in summer. As illustrated in FIG. **2**, the automotive air conditioner **40** transmits current setting parameters thereof to a second heat lost calculation unit **106** (described later) of the thermal sensation estimation apparatus **10**. The setting parameters are information indicating the air volume (small or large), wind direction (feet or the upper half of the body), and air temperature (cold or warm) of the automotive air conditioner **40** and the like.

As the setting parameters of the automotive air conditioner **40**, one or a plurality of pieces of information used by the automotive air conditioner **40** to set the air temperature and the air volume may be used. The plurality of pieces of information include, for example, a) the intensity of sunlight obtained by an actinometer, b) an outside temperature obtained by an outside temperature sensor, c) an inside temperature obtained by an inside temperature sensor, d) an engine coolant temperature obtained by an engine coolant temperature sensor, e) an evaporator wind temperature obtained by a thermometer at an end of an evaporator, f) an inside setting temperature input by a user, g) a blower motor voltage for controlling the wind speed of a blower, h) an air mixture door opening for controlling a mixture ratio of cool air and warm air, i) a necessary air temperature indicating a temperature of air to be blown, j) an air outlet mode indicating feet, a face, or both, and k) an air inlet mode indicating inside air or outside air.

As illustrated in FIGS. **1** and **2**, the thermal sensation estimation apparatus **10** includes a thermometer **101**, a wind speed/air temperature sensor **102**, a first thermal camera **103**, a second thermal camera **104**, a first heat loss calculation unit **105**, the second heat loss calculation unit **106**, an area ratio calculation unit **107**, a total heat loss calculation unit **108**, a thermal sensation estimation unit **109**, and a control unit **110**.

The thermometer **101** is provided at an air intake port (an example of a certain position around the person **30**) of the automotive air conditioner **40** and measures a temperature inside the vehicle body **201** (an example of a temperature around the person **30**).

The wind speed/air temperature sensor **102** measures a wind speed and an air temperature around a position (e.g., an abdomen of the person **30**) at which the person **30** is blown by air from the automotive air conditioner **40**. For example, the wind speed/air temperature sensor **102** measures a wind speed and an air temperature for each pattern of the setting parameters of the automotive air conditioner **40** before the automobile **20** is shipped. The wind speed/air temperature sensor **102** transmits the measured wind speed and air temperature to the second heat loss calculation unit **106**, in which the measured wind speed and air temperature are stored.

The first thermal camera **103** and the second thermal camera **104** detect infrared light radiated from objects and capture thermal images indicating thermal distribution in space. The first thermal camera **103** and the second thermal camera **104** are provided at different positions in the vehicle body **201**. More specifically, as illustrated in FIG. **1**, the first thermal camera **103** is mounted on a dashboard of the vehicle body **201**, for example, and captures a thermal image (an example of a first thermal image) of a lower half of the body of the person **30** in the seat **202** from the front. The second thermal camera **104** is mounted on a rearview mirror of the vehicle body **201**, for example, and captures a thermal image (an example of second thermal image) of the upper half of the body of the person **30** in the seat **202** from the front.

As illustrated in FIG. **3**, the first thermal camera **103** and the second thermal camera **104** obtain a thermal image of an area including a whole body of the person **30** viewed from the front by combining a thermal image of the lower half of the body of the person **30** and a thermal image of the upper half of the body of the person **30** viewed from the front. In the thermal image illustrated in FIG. **3**, the automotive air conditioner **40** blows cold air to the abdomen of the person **30**. A decrease in the temperature of the abdomen of the person **30** is represented by changes in color.

In the following description, a part of a human body surface area, which includes skin and clothes of the person **30**, in a thermal image not exposed to air from the automotive air conditioner **40** (exposed to a first thermal environment) will be referred to as a windless area **301** (an example of a first area). On the other hand, a part of a human body surface area in a thermal image exposed to air from the automotive air conditioner **40** (exposed to a second thermal environment different from the first thermal environment) will be referred to as a wind area **302** (an example of a second area). In the thermal image illustrated in FIG. **3**, the wind area **302** is the abdomen of the person **30** and identified from the second thermal image. The windless area **301** is a part other than the abdomen of the person **30** and identified from the first and second thermal images.

The first heat loss calculation unit **105** calculates the amount of heat convected in the windless area **301** (an example of a first amount of heat lost), which is the amount of heat lost from the windless area **301** of the person **30** in a unit area. The first heat loss calculation unit **105** also calculates the total amount of heat radiated, which is the amount of heat lost from the whole body (the windless area **301** and the wind area **302**) of person **30** in a unit area.

The amount of heat convected in the windless area **301** is the amount of heat lost through convection between air and the person **30** in the windless area **301**. The amount of heat convected in the windless area **301** is calculated by a calculation method in which a difference between an average surface temperature of the person **30** in the windless area **301** (an average surface temperature of a part of a human body surface area exposed to the first thermal environment; an example of a first temperature) and a temperature inside the vehicle body **201** (an example of first information indicating thermal characteristics of the first thermal environment) is multiplied by a convective heat transfer coefficient (an example of a certain value) under windless conditions. The average surface temperature of the person **30** in the windless area **301** is obtained from thermal images captured by the first thermal camera **103** and the second thermal camera **104**. The temperature inside the vehicle body **201** is, for example, measured by the thermometer **101**. Alternatively, an average temperature of a background image, which is a part of a thermal image other than the person **30**, may be used as the temperature inside the vehicle body **201**. The convective heat transfer coefficient under windless conditions is a fixed value set in advance.

The total amount of heat radiated is calculated by a calculation method in which a difference between an average radiation temperature (an example of the first information) around the person **30** and an average surface temperature of the whole body of the person **30** is multiplied by a radiative heat transfer coefficient. The average radiation temperature and the average surface temperature of the whole body of the person **30** are obtained from thermal images captured by the first thermal camera **103** and the second thermal camera **104**. Alternatively, an average temperature of a background image, which is a part of a thermal image other than the person **30**, may be used as the average radiation temperature. Alternatively, the average radiation temperature may be obtained by a globe thermometer (not illustrated) provided in the vehicle body **201**. The radiative heat transfer coefficient is a fixed value set in advance.

The second heat loss calculation unit **106** calculates the amount of heat convected in the wind area **302** (an example of a second amount of heat lost), which is the amount of heat lost from the wind area **302** of the person **30** in a unit area. The amount of heat convected in the wind area **302** is the amount of heat lost through convection between air and the person **30** in the wind area **302**. The amount of heat convected in the wind area **302** is calculated by a calculation method in which a difference between an average surface temperature of the person **30** in the wind area **302** (an average surface temperature of a part of a human body surface area exposed to the second thermal environment; an example of a second temperature) and an air temperature (an example of second information indicating thermal characteristics of the second thermal environment) is multiplied by a convective heat transfer coefficient (an example of a certain value) during air conditioning. The average surface temperature of the person **30** in the wind area **302** is obtained from thermal images captured by the first thermal camera **103** and the second thermal camera **104**. After the person **30** is seated in the seat **202** of the automobile **20** and the automotive air conditioner **40** begins to operate, the second heat loss calculation unit **106** reads the setting parameters of the automotive air conditioner **40** and a wind speed and an air temperature corresponding to the setting parameters. Alternatively, the second heat loss calculation unit **106** may estimate the wind speed and the air temperature by identifying a position of the person **30** in the vehicle body **201** using the setting parameters and thermal images.

The second heat loss calculation unit **106** sets the convective heat transfer coefficient during air conditioning on the basis of the read wind speed (an example of the second information). Alternatively, the second heat loss calculation unit **106** may store in advance a table in which wind speed and the convective heat transfer coefficient are associated with each other, for example, and read a convective heat transfer coefficient during air conditioning corresponding to the wind speed.

In general, the person **30** loses heat to the outside through a) convection (includes conduction), b) radiation, and c) expiration and the evaporation of perspiration. Expiration and the evaporation of perspiration remain constant when the person **30** is at rest. The first heat loss calculation unit **105** and the second heat loss calculation unit **106**, therefore, as described above, calculate the amount of heat lost through convection and the amount of heat lost through radiation, which are dominant factors in determining thermal sensation. Specific calculation methods used by the first heat loss calculation unit **105** and the second heat loss calculation unit **106** will be described later.

The area ratio calculation unit **107** calculates a ratio of an area of the wind area **302** of the person **30** in thermal images captured by the first thermal camera **103** and the second thermal camera **104** to an area of the whole body (the windless area **301** and the wind area **302**) of the person **30**. Because the area of the wind area **302** can be calculated on the basis of the wind direction and a wind range of the automotive air conditioner **40**, the area of the wind area **302** may be measured in advance, for example, before the automobile **20** is shipped. Since the area of the whole body of the person **30** varies depending on physical features of the person **30**, the area of the whole body of the person **30** is calculated from thermal images each time the automotive air conditioner **40** begins to operate. Alternatively, if a temperature histogram of a human body surface area of thermal images is obtained, for example, a peak of the wind area **302** at which temperature drops and a peak of the windless area **301** at which temperature does not drop are observed. The area ratio calculation unit **107** may calculate the ratio of the area of the wind area **302** of the person **30** to the area of the whole body of the person **30** on the basis of areas of these peaks. Alternatively, the area ratio calculation unit **107** may use a preset value as the ratio.

The total heat loss calculation unit **108** calculates the total amount of heat convected by weight-averaging the amount of heat convected in the windless area **301** calculated by the first heat loss calculation unit **105** and the amount of heat convected in the wind area **302** calculated by the second heat loss calculation unit **106** using the ratio calculated by the area ratio calculation unit **107**. The total amount of heat convected refers to the amount of heat lost from the whole body (the windless area **301** and the wind area **302**) of the person **30** in a unit area. The total heat loss calculation unit **108** also calculates the total amount of heat lost by adding the total amount of heat convected and the total amount of heat radiated calculated by the first heat loss calculation unit **105** and multiplying a result of the addition by a certain area ratio. The total amount of heat lost is the amount of heat lost from the whole body of the person **30** in a unit area. A specific calculation method used by the total heat loss calculation unit **108** will be described later.

The thermal sensation estimation unit **109** estimates the thermal sensation of the person **30** on the basis of the total amount of heat lost calculated by the total heat loss calculation unit **108**. A specific estimation method used by the thermal sensation estimation unit **109** will be described later.

The control unit **110** transmits (outputs), to the automotive air conditioner **40**, instruction information for controlling at least one of the air volume, air temperature, and wind direction of the automotive air conditioner **40** on the basis of thermal sensation estimated by the thermal sensation estimation unit **109**. Setting parameters of the automotive air conditioner **40** controlled on the basis of a thermal sensation include a) the blower motor voltage for controlling the wind speed of the blower, b) the air mixture door opening for controlling the mixture ratio of cool air and warm air, c) the necessary air temperature indicating the temperature of air to be blown, d) the air outlet mode indicating feet, a face, or both, and k) the air inlet mode indicating inside air or outside air. The evaporator temperature and the engine coolant temperature may also be controlled, if possible.

Some or all of the first heat loss calculation unit **105**, the second heat loss calculation unit **106**, the area ratio calculation unit **107**, the total heat loss calculation unit **108**, the thermal sensation estimation unit **109**, and the control unit **110** may be achieved as software by a processor (not illustrated), which is included in the thermal sensation estimation apparatus **10**, that executes a program, or may be achieved as hardware by a dedicated circuit. Information used by the above components for their respective processes is stored in a memory (not illustrated) or a storage (not illustrated) included in the thermal sensation estimation apparatus **10**.

1-2. Operation of Thermal Sensation Estimation Apparatus

Next, the operation (the method for estimating thermal sensation) of the thermal sensation estimation apparatus **10** according to the first embodiment will be described with reference to FIG. **4**. FIG. **4** is a flowchart illustrating a procedure of the operation of the thermal sensation estimation apparatus **10** according to the first embodiment.

As illustrated in FIG. **4**, first, before the automobile **20** is shipped, for example, the wind speed/air temperature sensor **102** measures the wind speed and the air temperature of the automotive air conditioner **40** for each pattern of the setting parameters of the automotive air conditioner **40** and stores the measured wind speed and air temperature in the second heat loss calculation unit **106** (S**101**).

After the person **30** gets in the automobile **20** and the automotive air conditioner **40** begins to operate, the setting parameters of the automotive air conditioner **40** are set (S**102**).

The first thermal camera **103** and the second thermal camera **104** then capture thermal images of the whole body of the person **30** from the front (S**103**).

The second heat loss calculation unit **106** then reads a wind speed corresponding to the setting parameters set in step S**102** and sets a convective heat transfer coefficient hcw during air conditioning on the basis of the read wind speed (S**104**).

The second heat loss calculation unit **106** then obtains an average surface temperature Tcw in the wind area **302** on the basis of the thermal images captured in step S**103**. The second heat loss calculation unit **106** also reads an air temperature Tw corresponding to the setting parameters set in step S**102**. The second heat loss calculation unit **106** calculates an amount Hcw of heat convected in the wind area **302** using a calculation method in which a difference between the average surface temperature Tcw in the wind area **302** and the air temperature Tw is multiplied by the convective heat transfer coefficient hcw during air conditioning as in expression (1) (S**105**).

$$Hcw = hcw \times (Tcw - Tw) \quad (1)$$

Hcw: Amount of heat convected in wind area
hcw: Convective heat transfer coefficient during air conditioning
Tw: Air temperature
Tcw: Average surface temperature in wind area

The first heat loss calculation unit **105** then obtains an average surface temperature Tcnw in the windless area **301** on the basis of the thermal images captured in step S**103**. The first heat loss calculation unit **105** also obtains a temperature Ta inside the vehicle body **201** measured by the thermometer **101**. The first heat loss calculation unit **105** calculates an amount Hcnw of heat convected in the windless area **301** using a calculation method in which a difference between the average surface temperature Tcnw in the windless area **301** and the temperature Ta is multiplied by a convective heat transfer coefficient hcnw under windless conditions as in expression (2) (S**106**).

$$Hcnw = hcnw \times (Tcnw - Ta) \quad (2)$$

Hcnw: Amount of heat convected in windless area
hcnw: Convective heat transfer coefficient under windless conditions
Ta: Temperature
Tcnw: Average surface temperature in windless area

The area ratio calculation unit **107** then calculates a ratio Ww (=Wa/Wt) of an area Wa of the wind area **302** of the person **30** to an area Wt of the whole body of the person **30** on the basis of the thermal images captured in step S**103**. The total heat loss calculation unit **108** then calculates a total amount Hc of heat convected by weight-averaging the amount Hcw of heat convected in the wind area **302** and the amount Hcnw of heat convected in the windless area **301** using the ratio Ww (S**107**).

$$Hc = Ww \times Hcw + (1 - Ww) \times Hcnw \quad (3)$$

Hc: Total amount of heat convected
Ww: Ratio of area of wind area to area of whole body

The first heat loss calculation unit **105** then obtains an average radiation temperature Tr and an average surface temperature Tc of the whole body on the basis of the thermal images captured in step S**103**. The first heat loss calculation unit **105** calculates a total amount Hr of heat radiated using a calculation method in which a difference between the average surface temperature Tc of the whole body and the average radiation temperature Tr is multiplied by the radiative heat transfer coefficient hr as in expression (4) (S**108**).

$$Hr = hr \times (Tc - Tr) \quad (4)$$

Hr: Total amount of heat radiated
hr: Radiative heat transfer coefficient
Tc: Average surface temperature of whole body
Tr: Average radiation temperature

The total heat loss calculation unit **108** then adds the total amount Hc of heat convected and the total amount Hr of heat radiated as in expression (5). The total heat loss calculation unit **108** also calculates a total amount H of heat lost by multiplying a result of the addition by 1−Ws, which is a ratio (Wb/Wt) of an area Wb of an insulated part **303** of the person **30** (a part of the person **30** insulated by the seat **202**) to the area Wt of the whole body of the person **30**, as in expression (5) (S**109**).

$$H = (Hc + Hr) \times (1 - Ws) \quad (3)$$

H: Total amount of heat lost
Ws: Ratio of area of insulated part **303** to area of whole body

The thermal sensation estimation unit **109** then estimates a thermal sensation Ts on the basis of the total amount H of heat lost as in expression (6) (S**110**). The thermal sensation Ts ranges, for example, from "−4" (cold) to "+4" (hot). A central value "0" (neutral) of the thermal sensation Ts**1** indicates a comfortable state.

$$Ts = a \times H + b \quad (6)$$

Ts: Thermal sensation
a: Coefficient
b: Y-intercept

The control unit **110** then transmits instruction information to the automotive air conditioner **40** on the basis of the estimated thermal sensation Ts (S**111**). As a result, at least one of the air volume, air temperature, and wind direction of the automotive air conditioner **40** is controlled such that, for example, the thermal sensation Ts becomes close to the value (neutral value) at which the person **30** does not feel cold or hot.

1-3. Advantageous Effects

As described above, when a part of a human body surface area is exposed to air from the automotive air conditioner **40**, for example, the thermal sensation estimation apparatus **10** according to the present embodiment calculates the amount of heat lost in the wind area **302** and the amount of heat lost in the windless area **301** and then calculates the total amount of heats lost by combining the amount of heat lost in the wind area **302** and the amount of heat lost in the windless area **301** using an area ratio. The thermal sensation estimation apparatus **10** then estimates thermal sensation on the basis of the total amount of heat lost calculated in this manner. That is, since the thermal sensation estimation apparatus **10** calculates the total amount of heat lost in consideration of the human body surface area exposed to a non-uniform thermal environment, the thermal sensation estimation apparatus **10** can accurately estimate thermal sensation even if the person **30** is in a non-uniform thermal environment.

By installing the thermal sensation estimation apparatus **10** in the automobile **20**, for example, the automotive air conditioner **40** can be controlled such that the thermal sensation becomes close to a value at which the person **30** does not feel cold or hot. As a result, the automotive air conditioner **40** does not cool or heat too much, and power is saved. The power that would otherwise be consumed by the automotive air conditioner **40**, therefore, can be used to drive the automobile **20**, and the automobile **20** can travel a longer distance.

Furthermore, since the thermal sensation estimation apparatus **10** according to the present embodiment estimates thermal sensation on the basis of the total amount of heat lost from the whole body of the person **30** in a unit area, the thermal sensation estimation apparatus **10** can estimate thermal sensation that does not depend on the physical features of the person **30**.

## Second Embodiment

### 2-1. Configuration of Thermal Sensation Estimation Apparatus

Next, the configuration of a thermal sensation estimation apparatus **10**A according to a second embodiment will be described with reference to FIGS. **5** and **6**. FIG. **5** is a diagram illustrating a use case of the thermal sensation estimation apparatus **10**A according to the second embodiment. FIG. **6** is a block diagram illustrating the configuration of the thermal sensation estimation apparatus **10**A according to the second embodiment. In the present embodiment, the same components as those according to the first embodiment are given the same reference numerals, and description thereof is omitted.

In the present embodiment, a case will be described in which the automotive air conditioner **40** performs a heating operation in winter. As illustrated in FIG. **5**, seat heaters **203** for heating a back of the person **30** are provided in the seat **202** of the automobile **20**.

As illustrated in FIGS. **5** and **6**, the thermal sensation estimation apparatus **10**A includes heat flow meters **112**, a third heat loss calculation unit **113**, and a hygrometer **114** in addition to the components described in the first embodiment.

As illustrated in FIG. **5**, the heat flow meters **112** are provided on the seat heaters **203** and measure the amount of heat transferred from the seat heaters **203** to the person **30** (an example of the amount of heat transferred between the seat **202** and the person **30**). Alternatively, the heat flow meters **112** may measure the amount of heat that the seat heaters **203** receive from the person **30** (an example of the amount of heat transferred between the seat **202** and the person **30**).

The third heat loss calculation unit **113** calculates the amount of heat conducted (an example of a third amount of heat lost) in a seat part **304** (an example of a third area), in which the person **30** is in contact with the seat heaters **203**, of the human body area. More specifically, the third heat loss calculation unit **113** calculates a reciprocal of the amount of heat transferred from the seat heaters **203** to the person **30** measured by the heat flow meters **112** as the amount of heat conducted in the seat part **304**.

Although the third heat loss calculation unit **113** calculates the amount of heat conducted using the heat flow meters **112** in the present embodiment, the components used by the third heat loss calculation unit **113** to calculate the amount of heat conducted are not limited to this. For example, thermometers (not illustrated) may be provided on the seat heaters **203** instead of the heat flow meters **112**. In this case, the third heat loss calculation unit **113** calculates the amount of heat conducted on the basis of temperatures calculated by the thermometers. Alternatively, the heat flow meters **112** may be omitted. In this case, the third heat loss calculation unit **113** calculates (estimates) the amount of heat conducted on the basis of power (current) supplied to the seat heaters **203**.

The hygrometer **114** is provided inside the vehicle body **201** of the automobile **20** and measures a humidity (an example of a thermal environment) inside the vehicle body **201**. The hygrometer **114** transmits humidity information regarding the measured humidity to a first heat loss calculation unit **105**A. The first heat loss calculation unit **105**A corrects the convective heat transfer coefficient hcnw under windless conditions in accordance with the received humidity information.

The third heat loss calculation unit **113** may be achieved as software by a processor (not illustrated), which is included in the thermal sensation estimation apparatus **10**A, that executes a program, or may be achieved as hardware by a dedicated circuit. Information used by the third heat loss calculation unit **113** to perform a process is stored in a memory (not illustrated) or a storage (not illustrated) included in the thermal sensation estimation apparatus **10**A.

### 2-2. Operation of Thermal Sensation Estimation Apparatus

Next, the operation (the method for estimating thermal sensation) of the thermal sensation estimation apparatus **10**A according to the second embodiment will be described with reference to FIG. **7**. FIG. **7** is a flowchart illustrating a procedure of the operation of the thermal sensation estimation apparatus **10**A according to the second embodiment. In FIG. **7**, the same steps as those according to the first embodiment illustrated in FIG. **4** are given the same reference numerals, and description thereof is omitted.

First, as in the first embodiment, steps S**101** to S**105** are performed. The first heat loss calculation unit **105**A then corrects the convective heat transfer coefficient hcnw under windless conditions in accordance with humidity information from the hygrometer **114** to obtain a convective heat transfer coefficient hcnw' under windless conditions (S**201**).

The first heat loss calculation unit **105**A then calculates the amount Hcnw of heat convected in the windless area **301** based on the humidity using a calculation method in which the difference between the average surface temperature Tcnw in the windless area **301** (refer to FIG. **3**) and the temperature Ta is multiplied by the convective heat transfer coefficient hcnw' under windless conditions as in expression (7) (S**202**).

$$Hcnw=hcnw'\times(Tcnw-Ta) \tag{7}$$

Hcnw: Amount of heat convected in windless area based on humidity

hcnw': Convective heat transfer coefficient under windless conditions

Ta: Temperature

Tcnw: Average surface temperature in windless area

Steps S**107** and S**108** are then performed as in the first embodiment. The third heat loss calculation unit **113** then calculates the reciprocal of the amount of heat transferred from the seat heaters **203** to the person **30** measured by the heat flow meters **112** as the amount Hcd of heat conducted in the seat part **304** (S**203**).

A total heat loss calculation unit **108**A then calculates the total amount H of heat lost by weight-averaging the total amount Hc of heat convected, the total amount Hr of heat radiated, and the amount Hcd of heat conducted using an area ratio Wst as in expression (8) (S204).

$$H=(Hc+Hr)\times(1-Wst)+Wst\times Hcd \quad (8)$$

H: Total amount of heat lost
Wst: Ratio of area of seat part **304** to area of whole body
Hcd: Amount of heat conducted

Steps S**110** and S**111** are then performed as in the first embodiment.

2-3. Advantageous Effects

As described above, the thermal sensation estimation apparatus **10**A according to the present embodiment calculates the amount of heat lost in the wind area **302** (refer to FIG. **3**) and the amount of heat lost in the windless area **301**, calculates the reciprocal of the amount of heat transferred from the seat heaters **203** to the person **30** as the amount Hcd of heat conducted in the seat part **304**, and calculates the total amount of heat lost by combining these using an area ratio. As a result, thermal sensation can be accurately estimated as in the first embodiment even in a non-uniform thermal environment in which, for example, the automotive air conditioner **40** and the seat heaters **203** heat the air inside the vehicle body **201** in winter.

Modifications

Although the method for estimating thermal sensation and the like according to one or a plurality of aspects have been described on the basis of the first and second embodiments, the present disclosure is not limited to the first and second embodiments. The one or plurality of aspects may also include modes obtained by modifying the first or second embodiment in various ways conceivable by those skilled in the art and modes constructed by combining different components in the first and second embodiments insofar as the scope of the present disclosure is not deviated from. For example, the first and second embodiments may be combined with each other.

Although the seat heaters **203** for heating the back of the person **30** are provided in the seat **202** in the second embodiment, for example, a steering wheel heater for heating hands of the person **30** may be provided in a steering wheel **204** (refer to FIG. **5**), instead. In this case, the steering wheel **204** is provided with a heat flow meter or a thermometer for measuring the amount of heat transferred between the steering wheel **204** and the person **30**. In this case, too, the amount of heat lost can be calculated using the same method as above.

Although the air conditioner is the automotive air conditioner **40** in the above embodiments, for example, the air conditioner may be a spot air conditioner installed in a room, instead.

Although the vehicle is the automobile **20** in the above embodiments, for example, the vehicle may be a train, an airplane, or the like, instead.

Although the thermal sensation estimation apparatus **10** (**10**A) is installed in the automobile **20** in the above embodiments, for example, the thermal sensation estimation apparatus **10** (**10**A) may be installed in a room of a house, instead.

Some or all of the components of the apparatuses may be achieved by an integrated circuit (IC) card or a separate module removably attached to the apparatuses. The IC card or the module is a computer system including a microprocessor, a read-only memory (ROM), and a random-access memory (RAM). The IC card or the module may include a super-multifunctional large-scale integration (LSI) circuit. When the microprocessor operates in accordance with a computer program, the IC card or the module achieves functions thereof. The IC card or the module may be tamper-resistant.

The present disclosure may be the above-described methods. The present disclosure may be a computer program that achieves these methods using a computer, or may be a digital signal including the computer program. The present disclosure may be a computer-readable recording medium storing the computer program or the digital signal, such as a flexible disk, a hard disk, a CD-ROM, a magneto-optical (MO) disk, a digital versatile disc (DVD), a DVD-ROM, a DVD-RAM, a Blu-ray Disc (BD; registered trademark), or a semiconductor memory. The present disclosure may be the digital signal stored in the recording medium. The present disclosure may be the computer program or the digital signal transferred through an electrical communication line, a wireless or wired communication line, a network typified by the Internet, datacasting, or the like. The present disclosure may be a computer system including a microprocessor and a memory. The memory may store the computer program, and the microprocessor may operate in accordance with the computer program. The present disclosure may be implemented by another independent computer system by transferring the program or the digital signal stored in the recording medium or by transferring the program or the digital signal through the network or the like.

The present disclosure can be used, for example, for a method for estimating thermal sensation.

What is claimed is:

**1**. A method used by a thermal sensation estimation apparatus, the method comprising:
- obtaining a thermal image of an area including a person captured by a thermal camera;
- calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment;
- calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment;
- calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment;
- obtaining an area ratio of the first area to the second area;
- calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio; and
- estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

**2**. The method according to claim **1**,
- wherein the first area includes at least a part of the human body surface area not exposed to air from an air conditioner, and
- wherein the second area includes at least a part of the human body surface area exposed to the air from the air conditioner.

3. The method according to claim 1, wherein the total amount of heat lost is calculated by weight-averaging the first amount of heat lost and the second amount of heat lost using the area ratio.

4. The method according to claim 1, wherein the area ratio is calculated on the basis of an area of the first area and an area of the second area in the thermal image.

5. The method according to claim 1, wherein the area ratio is calculated on the basis of a temperature histogram of the thermal image.

6. The method according to claim 1, wherein the area ratio is a preset value.

7. The method according to claim 1, wherein the thermal camera includes a first thermal camera provided at a certain position and a second thermal camera provided at a position different from that of the first thermal camera,

wherein the thermal image includes a first thermal image captured by the first thermal camera and a second thermal image captured by the second thermal camera,

wherein the first area is identified from the first thermal image, and

wherein the second area is identified from the second thermal image.

8. The method according claim 1, wherein the person is in contact with a certain member,

wherein an amount of heat transferred between the person and the certain member in a third area, which is a part of the human body surface area in which the person is in contact with the certain member, is calculated on the basis of an amount of heat received by or lost from the certain member,

wherein an area ratio of the first area, the second area, and the third area is obtained, and

wherein the total amount of heat lost is calculated on the basis of the first amount of heat lost, the second amount of heat lost, the amount of heat transferred, and the area ratio.

9. The method according to claim 8, wherein the certain member is at least either a seat of a vehicle in which the person stays or a steering wheel, and

wherein the amount of heat transferred is an amount of heat transferred on a surface of the person's body at which the person is in contact with at least either the seat or the handle.

10. The method according to claim 9, wherein the amount of heat transferred is measured by a thermometer provided for at least either the seat or the steering wheel.

11. The method according to claim 9, wherein the amount of heat transferred is measured by a heat flow meter provided for at least either the seat or the steering wheel.

12. The method according to claim 1, wherein at least either the first information or the second information includes a temperature around the person.

13. The method according to claim 12, wherein at least either the first amount of heat lost or the second amount of heat lost is calculated by a calculation method in which a difference between the first temperature or the second temperature, whichever corresponds to the amount of heat lost, and the temperature is multiplied by a certain value.

14. The method according to claim 12, wherein the temperature is calculated on the basis of a thermal image representing temperature distribution in space.

15. The method according to claim 12, wherein the temperature is measured by a thermometer provided at a certain position around the person.

16. The method according to claim 1, wherein at least either the first information or the second information includes radiation temperature.

17. The method according to claim 16, wherein the radiation temperature is calculated on the basis of a thermal image representing temperature distribution in space.

18. The method according to claim 1, wherein at least either the first information or the second information includes wind speed and air temperature of wind around the person.

19. The method according to claim 18, wherein a convective heat transfer coefficient between the human body surface area and at least either the first thermal environment or the second thermal environment is set in accordance with the wind speed, and

wherein at least either the first amount of heat lost or the second amount of heat lost is calculated on the basis of the convective heat transfer coefficient, the air temperature, and the first temperature or the second temperature, whichever corresponds to the amount of heat lost.

20. The method according to claim 19, wherein at least either the first amount of heat lost or the second amount of heat lost is calculated by a calculation method in which a difference between the first temperature or the second temperature, whichever corresponds to the amount of heat lost, and the air temperature is multiplied by the convective heat transfer coefficient.

21. The method according to claim 19, wherein the wind speed and the air temperature are wind speed and air temperature of air from an air conditioner installed in space where the person stays.

22. The method according to claim 21, further comprising:

obtaining setting parameters of the air conditioner; and

calculating at least either the first amount of heat lost or the second amount of heat lost using the wind speed and the air temperature set using the setting parameters.

23. The method according to claim 22, further comprising:

measuring in advance the wind speed and the air temperature at each position in the space for each pattern of the setting parameters of the air conditioner;

estimating the wind speed and the air temperature in the human body surface area by identifying a position of the person in the space using the setting parameters of the air conditioner and the thermal image; and

calculating at least either the first amount of heat lost and the second amount of heat lost using the estimated wind speed and air temperature.

24. The method according to claim 1, wherein the first thermal environment and the second thermal environment include humidity around the person.

25. The method according to claim 1, further comprising:

outputting, to an air conditioner, instruction information for controlling air volume, air temperature, or wind direction of the air conditioner in accordance with the estimated thermal sensation.

26. The method according to claim 1,

wherein the thermal image is captured inside a vehicle body of a vehicle in which the person stays.

27. A thermal sensation estimation apparatus comprising:

a processor; and

a memory,

wherein the processor performs operations including

obtaining a thermal image of an area including a person captured by a thermal camera,

calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment,

calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment,

calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment,

obtaining an area ratio of the first area to the second area,

calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio, and

estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

28. An air conditioner comprising:

the thermal sensation estimation apparatus according to claim 27,

wherein air volume, air temperature, or wind direction is controlled on the basis of the thermal sensation estimated by the thermal sensation estimation apparatus.

29. A non-transitory recording medium storing a program for causing a computer to function as a thermal sensation estimation apparatus, the program causing the computer to perform operations comprising:

obtaining a thermal image of an area including a person captured by a thermal camera;

calculating, on the basis of the thermal image, a first temperature, which is a surface temperature of a first area, which is a part of a human body surface area including skin or clothes of the person, exposed to a first thermal environment, and a second temperature, which is a surface temperature of a second area, which is at least a part of the human body surface area other than the first area, exposed to a second thermal environment different from the first thermal environment;

calculating a first amount of heat lost, which is an amount of heat lost from the first area of the person in a unit area, on the basis of the first temperature and first information indicating thermal characteristics of the first thermal environment;

calculating a second amount of heat lost, which is an amount of heat lost from the second area of the person in a unit area, on the basis of the second temperature and second information indicating thermal characteristics of the second thermal environment;

obtaining an area ratio of the first area to the second area;

calculating a total amount of heat lost, which is an amount of heat lost from a whole body of the person in a unit area, on the basis of the first amount of heat lost, the second amount of heat lost, and the area ratio; and

estimating thermal sensation, which indicates a degree of warmth or coldness of the person, on the basis of the total amount of heat lost.

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